CollegeBoard
Advanced Placement Program

AP® Physics C: Mechanics
2006 Scoring Guidelines

General Notes About 2006 AP Physics Scoring Guidelines

1. The solutions contain the most common method of solving the free-response questions and the allocation of points for this solution. Some also contain a common alternate solution. Other methods of solution also receive appropriate credit for correct work.

2. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded. One exception to this may be cases when the numerical answer to a later part should be easily recognized as wrong, e.g., a speed faster than the speed of light in vacuum.

3. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth 1 point, and a student's solution contains the application of that equation to the problem but the student does not write the basic equation, the point is still awarded. However, when students are asked to derive an expression, it is normally expected that they will begin by writing one or more fundamental equations, such as those given on the AP Physics exam equation sheet. See pages 21–22 of the *AP Physics Course Description* for a description of the use of such terms as "derive" and "calculate" on the exams, and what is expected for each.

4. The scoring guidelines typically show numerical results using the value $g = 9.8 \text{ m/s}^2$, but use of 10 m/s^2 is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

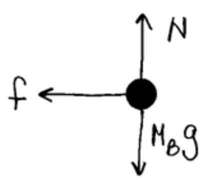
5. Strict rules regarding significant digits are usually not applied to numerical answers. However, in some cases answers containing too many digits may be penalized. In general, two to four significant digits are acceptable. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically receive full credit. Exceptions to these guidelines usually occur when rounding makes a difference in obtaining a reasonable answer. For example, suppose a solution requires subtracting two numbers that should have five significant figures and that differ starting with the fourth digit (e.g., 20.295 and 20.278). Rounding to three digits will lose the accuracy required to determine the difference in the numbers, and some credit may be lost.

Question 1

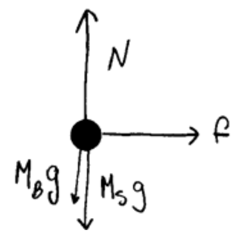
15 points total — **Distribution of points**

(a) 4 points

Block



Slab



For the block force diagram:

For correctly labeled horizontal force (friction to the left, no other forces or vectors) — 1 point

For correctly labeled vertical forces (normal up <u>and</u> weight down; gravity alone not accepted) — 1 point

For the slab force diagram:

For correctly labeled horizontal force (friction to the right, no other forces or vectors) — 1 point

For correctly labeled vertical forces (normal up <u>and</u> combined weight down; combined weight can be shown with two arrows <u>or</u> identifying weight as $W_S + W_B$ or $M_S g + M_B g$; gravity alone not accepted) — 1 point

(b) and (c)

These two parts were scored together because of the different approaches that could be used to answer them.

<u>Momentum approach to part (b); Newton's second law and kinematics approach to part (c)</u>

(b) 3 points

For any statement of conservation of momentum — 1 point

No net external forces act on the two-block system, so linear momentum is conserved.

For a correct momentum equation — 1 point

$M_B v_0 = (M_B + M_S) v_f$

$$v_f = \frac{M_B}{M_B + M_S} v_0 = \frac{0.50\text{ kg}}{0.50\text{ kg} + 3.0\text{ kg}} 4.0\text{ m/s}$$

For the correct answer — 1 point

$v_f = 0.57\text{ m/s}$

Question 1 (continued)

Distribution of points

Momentum approach (continued)

(c) 6 points

For a correct expression for the friction force (awarded if found in the solution to any of parts (a) through (d)) — 1 point

$f = \mu mg$ or $f = \mu N$

For correct substitution of $m = M_B$ for the friction force on the block — 1 point

$f = \mu M_B g$

For recognizing that the friction force on the slab is equal in magnitude to the friction force on the block and for an equation relating this force to the acceleration of the slab — 1 point

$f = M_S a_S$

For a correct expression for the acceleration of the slab or its numerical value — 1 point

$$a_S = \frac{\mu M_B g}{M_S} = 0.33 \text{ m/s}^2$$

For a correct kinematic equation for the slab — 1 point

$\upsilon_f^2 = \upsilon_0^2 + 2a_S x$, where $\upsilon_0 = 0$

$$x = \frac{\upsilon_f^2}{2a_S} = \frac{\upsilon_f^2}{2}\frac{M_S}{\mu M_B g}$$

For correct substitutions consistent with earlier values — 1 point

$$x = \frac{(0.57 \text{ m/s})^2}{2}\frac{3.0 \text{ kg}}{0.20(0.50 \text{ kg})\left(9.8 \text{ m/s}^2\right)}$$

x = 0.49 m or 0.50 m, depending on use of $g = 9.8$ or 10 m/s^2 and where substitution and rounding took place

Question 1 (continued)

Distribution of points

Newton's second law and kinematics approach to part (b); kinematics approach to part (c)

(b) 7 points

For a correct expression for the friction force (awarded if found in the solution to any of parts (a) through (d)) — 1 point

$f = \mu mg$ or $f = \mu N$

For correct substitution of $m = M_B$ — 1 point

$f = \mu M_B g$

For recognizing that the friction force on the slab is equal in magnitude to the friction force on the block and for an equation relating this force to the acceleration of the slab — 1 point

$f = M_S a_S$

For a correct expression for the acceleration of the slab or its numerical value — 1 point

$$a_S = \frac{\mu M_B g}{M_S} = 0.33 \text{ m/s}^2$$

For a correct expression for the acceleration of the block or its numerical value — 1 point

$$a_B = \frac{\mu M_B g}{M_B} = \mu g = 2.0 \text{ m/s}^2$$

For a solution of the following simultaneous kinematic equations for the block and the slab, such as by setting the times equal and solving for v_f — 1 point

$v_f = v_0 - a_B t$ for the block

$v_f = a_S t$ for the slab

$$v_f = \frac{a_S v_0}{a_S + a_B} = \frac{\left(0.33 \text{ m/s}^2\right)(4.0 \text{ m/s})}{0.33 \text{ m/s}^2 + 2.0 \text{ m/s}^2}$$

For the correct answer — 1 point

$v_f = 0.57 \text{ m/s}$

(c) 2 points

For a correct kinematic equation for the slab — 1 point

$v_f^2 = v_0^2 + 2a_S x$, where $v_0 = 0$

$$x = \frac{v_f^2}{2a_S} = \frac{v_f^2}{2}\frac{M_S}{\mu M_B g}$$

For correct substitutions consistent with earlier values — 1 point

$$x = \frac{(0.57 \text{ m/s})^2}{2}\frac{3.0 \text{ kg}}{0.20(0.50 \text{ kg})\left(9.8 \text{ m/s}^2\right)}$$

$x = 0.49$ m or 0.50 m, depending on use of $g = 9.8$ or 10 m/s^2 and where substitution and rounding took place

Question 1 (continued)

Distribution of points

(d) 2 points

For a correct expression for the work done — 1 point

$W = Fd = \mu M_B g x$ OR $W = \Delta K = \frac{1}{2} M_S v_f^2$

For consistent substitution from parts (b) and (c) — 1 point

$W = 0.20(0.5\text{ kg})\left(9.8\text{ m/s}^2\right)(0.50\text{ m})$ OR $W = \frac{1}{2}(3.0\text{ kg})(0.57\text{ m/s})^2$

$W = 0.49$ J (or $W = 0.50$ J using $g = 10\text{ m/s}^2$)

Question 2

15 points total | **Distribution of points**

(a) 1 point

For indicating that F vs. x^2 <u>or</u> $\sqrt{F}$ vs. x should be graphed, <u>or</u> other equivalent correct response (Must clearly specify two variables in order to earn this point.) — 1 point

(b) 2 points

For a correct column label, including units — 1 point
For calculated values that match what is indicated in (a) — 1 point
<u>Note</u>: If answer to (a) was incorrect or incomplete, (b) received no credit.

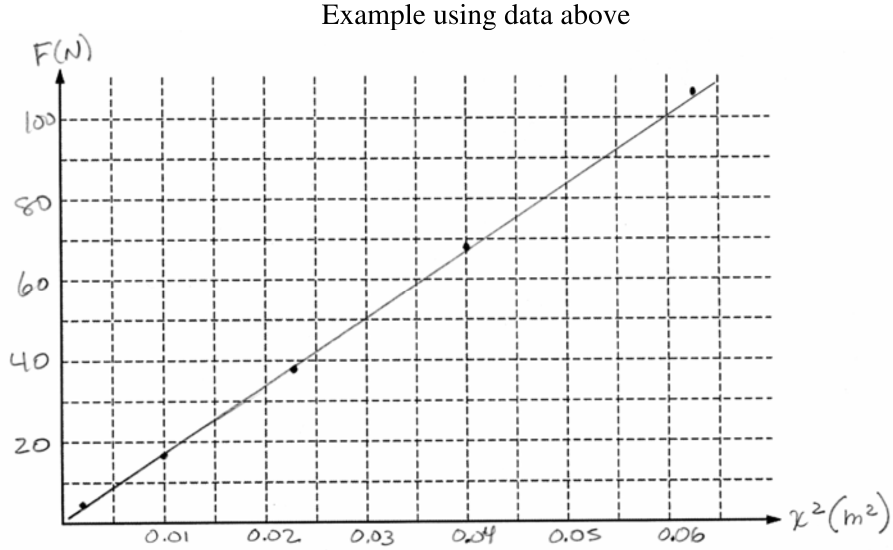
Example using F vs. x^2

x (m)	F (N)	x^2 (m^2)
0.05	4	0.0025
0.10	17	0.010
0.15	38	0.023
0.20	68	0.040
0.25	106	0.063

(c) 3 points

For appropriate linear axes scales — 1 point
For correct axes labels — 1 point
For plotting the points — 1 point
<u>Note</u>: Axes and scales must match answer in (a). However, if (a) was incorrect or incomplete, points were awarded in (c) if graph was executed correctly. If (a) was blank or didn't include any variables, no credit was awarded for (b) or (c).

Example using data above



Question 2 (continued)

	Distribution of points
(d) 2 points	
For indication of a correct relationship between the coefficient *A* and the slope for the values graphed in (c)	1 point
For correct units and no more than four significant figures on value of *A*	1 point

Example using data in the table and two points on the line in the graph

$F = Ax^2$, so A is equal to the slope of the F vs. x^2 line.

$$A = \text{ slope } = \frac{\Delta F}{\Delta x^2} = \frac{100\text{ N} - 50\text{ N}}{0.060\text{ m}^2 - 0.030\text{ m}^2} = 1.7 \times 10^3\ \text{N/m}^2$$

<u>Notes</u>:
This part stated to "calculate," so an answer with correct units and significant figures but with no work shown earned 1 point.
Since all the data points are on the best-fine line, additional credit was not awarded for a correctly drawn best-fine line or for use of points on the line instead of data points.

(e) 4 points

Using the definition of work

$$W = \int F\,dx$$

For correct substitution of $F(x)$ into the integral for work	1 point
For correct limits on the integral	1 point
For correct evaluation of the integral	1 point

$$W = \int_0^{0.10\text{ m}} Ax^2\,dx = \frac{1}{3}A(0.10\text{ m})^3 = \frac{1}{3}\left(1.7 \times 10^3\ \text{N/m}^2\right)\left(1.0 \times 10^{-3}\ \text{m}^3\right)$$

For the correct answer with correct units	1 point

$W = 0.57$ J

<u>Note</u>: *This part stated to "calculate," so a correct answer with correct units, but with no work shown, earned 1 point.*

(f) 3 points

For an appropriate expression of conservation of energy or the work-energy theorem	1 point
For a correct expression for *K* and substitution of *W* from part (e), expressed algebraically or numerically	1 point

$$W = \Delta K = \frac{1}{2}mv^2$$

$$v = \sqrt{\frac{2W}{m}} = \sqrt{\frac{2(0.57\text{ J})}{0.5\text{ kg}}}$$

For a value of v consistent with the value of *W* in (e), with correct units	1 point

$v = 1.5$ m/s

<u>Note</u>: *This part stated to "calculate," so an answer consistent with (e) and with correct units, but with no work shown, earned 1 point.*

Question 3

15 points total | **Distribution of points**

(a) and (b)
These two parts were scored together because of the different approaches that could be used to answer them. The parts could be answered in either order.

Approach using translational and rotational dynamics

(a) 5 points

For use of Newton's 2nd law in both translational and rotational forms — 1 point
$\sum F = ma_{cm}$ and $\sum \tau = I\alpha_{cm}$

For a correct equation applying Newton's second law in translational form — 1 point
$Mg\sin\theta - f = Ma_{cm}$

For a correct equation applying Newton's second law in rotational form — 1 point
$fR = I\alpha_{cm}$

For a correct relationship between linear and angular acceleration for rolling without slipping — 1 point

$\alpha_{cm} = \dfrac{a_{cm}}{R}$

Substituting for I and α_{cm} into the rotational equation above

$fR = MR^2 \dfrac{a_{cm}}{R}$

$f = Ma_{cm}$

Substituting this expression for f into the equation for translational motion above
$Mg\sin\theta - Ma_{cm} = Ma_{cm}$

For the correct answer — 1 point

$a_{cm} = \dfrac{g}{2}\sin\theta$

(b) 3 points

For a correct kinematic equation containing a and υ — 1 point
$\upsilon^2 = \upsilon_0^2 + 2a\Delta x$, $\upsilon_0 = 0$

For correct substitution of the expression for acceleration from part (a) — 1 point

For correct substitution of the distance traveled — 1 point

$\upsilon^2 = 2\left(\dfrac{g}{2}\sin\theta\right)L$

$\upsilon = \sqrt{gL\sin\theta}$

Question 3 (continued)

Distribution of points

Approach using torque about point of contact between hoop and ramp and parallel axis theorem

(a) 5 points

For use of Newton's 2nd law in rotational form and the parallel axis theorem $\sum \tau = I\alpha_{cm}$ and $I = I_{cm} + Mh^2$	1 point
For a correct rotational inertia about the point of contact using the parallel axis theorem $I = MR^2 + MR^2 = 2MR^2$	1 point
For a correct torque about the point of contact $\sum \tau = RMg\sin\theta$	1 point
For a correct relationship between linear and angular acceleration for rolling without slipping $\alpha_{cm} = \dfrac{a_{cm}}{R}$	1 point

Substituting for $\sum \tau$, I, and α_{cm} into the rotational equation above

$RMg\sin\theta = 2MR^2 \dfrac{a_{cm}}{R}$

For the correct answer $a_{cm} = \dfrac{g}{2}\sin\theta$	1 point

(b) 3 points

For a solution to part (b) as in the previous approach with points allotted similarly	3 points

Question 3 (continued)

Distribution of points

Approach using conservation of energy and kinematics, working part (b) first

(b) 5 points

For a statement of conservation of energy containing potential and kinetic energy terms — 1 point

$\Delta U = K_{rot} + K_{trans}$

For a correct expression for the potential energy change — 1 point

For correct translational and rotational kinetic energies — 1 point

$MgL\sin\theta = \frac{1}{2}M\upsilon^2 + \frac{1}{2}I\omega^2$

For a correct relationship between linear and angular velocity for rolling without slipping — 1 point

$\omega = \frac{\upsilon}{R}$

Substituting expressions for I and ω into the energy equation above

$MgL\sin\theta = \frac{1}{2}M\upsilon^2 + \frac{1}{2}\left(MR^2\right)\left(\frac{\upsilon}{R}\right)^2$

$gL\sin\theta = \frac{1}{2}\upsilon^2 + \frac{1}{2}\upsilon^2 = \upsilon^2$

For the correct answer — 1 point

$\upsilon = \sqrt{gL\sin\theta}$

(a) 3 points

For a correct kinematic relationship — 1 point

$\upsilon^2 = \upsilon_0^2 + 2a\Delta x$, $\upsilon_0 = 0$

For correct substitution of the expression for velocity — 1 point

For correct substitution of the distance traveled — 1 point

$gL\sin\theta = 2a_{cm}L$

$a_{cm} = \frac{g}{2}\sin\theta$

Question 3 (continued)

	Distribution of points
(c) 4 points	
Applying the kinematic equation for distance as a function of time to the vertical motion $H = gt^2/2$	
For a correct expression for the time between leaving the table and landing on the floor $t = \sqrt{2H/g}$	1 point
For use of zero acceleration in calculation of the horizontal distance traveled $x = \upsilon_x t$	1 point
For correct substitution of υ_x from part (b)	1 point
For correct substitution of *t* from previous calculation $d = \sqrt{gL\sin\theta}\sqrt{2H/g}$ $d = \sqrt{2LH\sin\theta}$	1 point

(d) 3 points

For checking the space next to "Greater than"	1 point
For a sufficiently detailed justification containing no incorrect statements. Such an answer logically concludes, at a minimum, that the linear speed or velocity at the bottom of the ramp is greater for the disk because the rotational inertia of the disk is less. It is not necessary to state that the time of fall is the same.	2 points

One point was awarded for a minimal or partially correct answer.
No justification points were awarded if the space next to "Greater than" was not checked.

Examples of 2-point answers:

A disk will have smaller rotational inertia and will therefore have a greater rotational velocity. This will lead to a greater translational velocity, and a greater distance *x*.

The rotational inertia is less than the hoop, causing greater acceleration and more final speed at the end of the table.

The acceleration when $I = MR^2/2$ is $(2/3)g\sin\theta$, so the disk will be moving faster at the bottom of the ramp and will travel farther.

Examples of 1-point answers:

A disk has a larger rotational inertia, so it will have a greater kinetic energy and will therefore land farther from the ramp.

The moment of inertia for the disk is smaller, thus its rotational velocity is bigger, causing it to go further.

Less energy will be used to spin the disk than the hoop, and *I* of the disk is less than *I* of the hoop.